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(54) FILTERING

FILTERVORRICHTUNG

FILTRAGE

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(56) References cited:
US-A- 3 828 281
US-A- 4 185 250

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Description

The present invention is concerned with filtering arrangements for use with telephone lines.

One situation in which such filtering is required is that of asymmetric digital subscriber line (ADSL) technology. This is a means of providing broadband digital services at rates of typically 1.5 to 6Mbit/s over local loop lines; this high transmission rate being provided in one direction only (exchange to customer).

In order to maintain the attractiveness of this proposal it is important that ADSL is multiplexed on top of ordinary telephone services (POTS). This multiplexing is achieved by frequency division, using cross-over filters which have become known as ADSL/POTS separation filters. Similar filters are required at both the local exchange and customer ends of the line. In principle identical filters may be used but the requirements at the exchange end are somewhat relaxed so an optimised design may use slightly different filters. This document concentrates on the customer end tilter which has the most challenging requirements, but the same problems are encountered with both filters.

Two particular aspects of telephone transmission systems requiere careful attention. One of these is the generation of massive transients, due to such activities as on/off hook switching, loop disconnect dialling, ring cadencing and ring trip. Of these probably the worst is ring trip which can generate transient peak voltages of some 100V. The second is the question of impedance balance.

In the UK (in common with many other parts of the world) non resistive frequency dependent impedances are used. The existing telephony access network infrastructure consists largely of twisted pairs of copper wires with polyethylene insulation, running from the local exchange to the customer's premises. The characteristic impedance Z_0 of such transmission lines is given by

$$Z_a = \sqrt{(R + j\omega L)} / \sqrt{(G + j\omega C)}$$

where R, L, G and C are the series resistance, inductance, shunt conductance and capacitance per unit length of the line, ω is the angular frequency and $j^2 = -1$.

Polyethylene is such a good insulator that G can be treated as zero whilst L (typically about 600mH/km) is, at telephony frequencies up to 4kHz, also negligible. Thus Z_0 can be approximated by

$$Z_0 \approx \sqrt{R / j\omega C} = (1-j)\sqrt{r / \omega C}$$

Typical values for R and C are 170 Ω/km and 50 nF/km so that at 1kHz Z_0 is approximately 520 - j520 ohm.

In the access network telephony transmission is 2-wire, bidirectional, with separation of signals travelling in the two directions being achieved by bridges in the telephone and at the exchange. This situation is shown diagrammatically in Figure 1. In a telephone 1, a microphone 2 is coupled via an amplifier 3 and an impedance 4 (Z_o ohms) to a balun transformer 5 and hence the twisted-pair transmission line 6. The impedance 4 and the line impedance form one arm of the bridge, the other being formed by further impedances 7 and 8 of Z_o and Z_{so} respectively. A differential amplifier 9 is connected across the bridge circuit and feeds an earpiece 10. Similarly at the exchange, the bridge comprises impedances 14, 17, 18, balun 15 and amplifiers 13, 19, the input impedance being Z_t and the impedance of the lower arm of the bridge Z_b.

It is apparent that the line 6 must present to the telephone 1 an impedance of Z_{so} in order to balance the bridge in the telephone and prevent the user from hearing his own voice ("sidetone"). On a short line, Z_t needs to equal Z_{so} to achieve balance, and similarly Z_c and Z_{so} need to be equal for balance at the exchange.

For longer lines, the impedance presented by the line will remain unchanged only if $Z_t = Z_c = Z_0$ and thus to keep both bridges balanced independent of line length ideally $Z_o = Z_{so} = Z_t = Z_b = Z_0$.

For various reasons (such as historical precedent, compromise across a variety of pair types and the convenience of a resistive reference impedance) few if any operators have ended up with such a network strategy. Sometimes Z_c and Z_t are resistive (600, 900 or even 1200 Ohm) and Z_b, Z_{so} chosen by compromise. In the UK all four impedances are different, frequency dependent and can be closely approximated by simple RC networks. A good compromise between these 4 impedances which can be used as the basis of ADSL/POTS separation filter design is given in Figure 2, and in this document it is called Zm.

The present invention provides a telecommunications station as defined by the appended claims comprising

a line connection connected to a transmission path having a frequency dependent characteristic impedance;
a high-pass filter connected between the line connection and means for transmitting and/or receiving signals in an upper frequency band;
a low-pass filter arrangement connected between the line connection and telephony apparatus for communication in a lower frequency band;
wherein the low-pass filter arrangement comprises a passive filter and impedance conversion arrangement having two ports connected respectively to the filter and to the transmission line;
each impedance conversion arrangement comprising a conductive path between the ports so as to be substantially transparent to d.c. and to components exceeding a predetermined amplitude, and an amplifier connected to receive signals from the conductive path and to deliver to the conductive path a

frequency-dependent function of the received signals.

Impedance-matching circuits are of course known per se; for example US patent 3,828,281 describes an impedance-simulating circuit for transmission lines where the line voltage is sensed and controls a current generator to draw current from the lines whilst the line current is sensed and controls a voltage generator to insert (via transformers) series voltages into the lines. The current and voltage generators can be connected to receive also, respectively, the currents and voltages sensed, to form an impedance matching network.

In a preferred embodiment of the invention the impedance converter has an amplifier for receiving the voltage at the first port and a transformer coupling the output of the amplifier between the ports such that the voltage at the second port is a predetermined function of that at the first, and the current at the two ports is the same.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 3 is a schematic diagram of a telecommunications station embodying the invention;
Figure 4 is a circuit diagram of one form of filter arrangement envisaged by the invention;
Figure 5 is a circuit diagram of a prototype filter on which the design of Figure 6 is based;
Figure 6 is a circuit diagram of a second embodiment of telecommunications station; and
Figure 7 is a circuit diagram of a current GIC, alternative to the voltage GIC shown in Figure 4.

Figure 3 shows the basic structure of separation filtering at the customer premises. A twisted pair line 100 from the local exchange (not shown) is connected to a line termination point 101. Two filters are connected in parallel to this point, namely a low-pass filter 102, connected via a telephone port 103, to a conventional telephone 104, and a high-pass filter 105 connected to an ADSL port 106 and hence to ADSL equipment 107.

The two filters have non-overlapping pass-bands so that, on the path from the telephone 104 to the ADSL equipment 107, transient energy from the telephone is attenuated at all frequencies from d.c. up to the region of 1MHz. Ideally, each filter is nearly lossless in its passband, with a high degree of rejection (typically 100dB or more) in the stopband. As they are connected in parallel, the filters need to have a high impedance (open circuit) at stopband frequencies. (An alternative configuration is a series connection, requiring low impedance in the stopband).

The lowpass filter needs a passband from d.c. to about 4kHz, and is subject to two particular sets of requirements. Firstly it needs to be transparent to passage of ringing and line power from the line 100 to the telephone 104. As discussed earlier, it needs to be able to handle high-voltage transients without difficulty. (Also it should have virtually no impact on the operation of conventional line systems, thus requiring low leakage and low capacitance). Secondly the filter impedance characteristics need to be such that bridge balance of (unmodified) telephones and exchange equipment is unaffected. Ideally this means that the characteristic impedance is the same as that of the line 100 - i.e. Zm.

The characteristic impedance of a filter is that value of load impedance to the filter which minimises the frequency dependence of the impedance looking into the filter input. For a ripple-free (i.e. lossless) filter this is the same as defining the characteristic impedance as that load impedance which results in the same value of impedance looking into the filter input (as with a transmission line).

These two requirements are mutually conflicting; the first requirement is difficult to meet using active filters, because of the problem of passing d.c., and the presence of large voltages such as ringing current and power feeding. It is undesirable to process these signals using operational amplifier circuits because of the large voltages involved. Also there is a need to maintain dielectric isolation between the wires of the pair and between each wire and ground both for safety reasons and to minimise problems with network test equipment which might otherwise report a fault on the line. Further there is a need to maintain very good linearity in the circuit because distortion, particularly of the ADSL signal, would seriously compromise system performance.

The second requirement cannot be met with passive filters since these have a real (resistive) characteristic impedance whilst the characteristic impedance of the transmission line 100 is - as discussed in the introduction - strongly frequency dependent.

Figure 4 shows one example of a filter arrangement as envisaged by the invention. It comprises a passive filter 200 shown here as a simple pi filter with an inductor 201 and capacitors 202, 203, although a higher order filter would be needed (as discussed below) to attain the sort of rejection levels discussed carlier. The passive filter provides the desired performance for large signals but does not meet the impedance requirement. However both the input and output of the filter 200 are connected inside a back-to-back pair of Generalised Immittance Converters (GIC) 300, 400 (The terms "input" and "output" are used here for convenience, but of course the filter arrangement passes signals in both directions).

The GIC is a two port device which acts to transform the impedance between the filter and the external circuitry connected to it. It behaves rather like a transformer but instead of multiplying the impedance by a real factor it changes it by any desired transfer function h(s).

There area number of different designs of GIC; in particular the voltage GIC modifies the voltage between the two ports whilst leaving the current unchanged, whilst in a current GIC the reverse is true. The GIC 300

used in figure 4 is a voltage GIC of unconventional construction in which a high gain inverting amplifier 301 receives (via a d.c. blocking capacitor 302 and resistor (value R) 303 the voltage at the right-hand port. The amplifier has a negative feedback path of impedance R (h (s) - 1) and its output is connected via a transformer 304 between left and right-hand ports.

The impedance seen looking into the left-hand port of the GIC 300 is h(s) times the impedance seen looking into the left-hand side of the filter 200. Thus if (for example) the filter 200 has a characteristic impedance Z_0 = 320 Ω and is to be matched to the reference impedance Zm, then h(s) needs to be chosen such that Zm = 320 h(s). Thus h(s) - 1 = (Zm - 320)/320. Reference to Figure 2 shows that Zm - 320 is just a parallel RC circuit and thus the feedback impedance in Figure 4 is too, viz, a resistor 305 and capacitor 306. The GIC 400 is identical to the GIC 300. This is however not always essential; indeed in a situation where the telephone is not well matched to the transmission line the balance may be improved by deliberately providing different GIC's so that the GIC 300 provides good matching between the telephone and the filter and the GIC 400 provides a good match between the filter and the line.

It is observed that this particular construction of the GIC, with the transformer 304 and the blocking capacitor 302, is such that d.c. components are unaffected by it; in particular line power and ringing current can pass unimpeded. Large transients can pass, simply causing saturation of the amplifier (the input and/or output of the amplifier can be provided with clamping diodes if necessary).

In an alternative arrangement, a current GIC would employ a current transformer to sense the line current, and an amplifier (with the desired transfer function) having a current (i.e. high impedance) output to drive a corresponding current into/from the line.

For clarity, the filter arrangement of Figure 4 is ground referenced, but a balanced filter can be readily constructed, as will shortly be described. First, however, an unbalanced 7th order passive filter is shown for reference in Figure 5. It is a modified elliptic filter with only two pairs of transmission zeros. It has inductors L4, L5, (with capacitors C5, C7) L8, and shunt capacitors C4, C6, C8 and C11. Note that the inductor L8 has no capacitor in parallel, to prevent loading of the high-pass filter in the low-pass filter stopband.

Figure 6 shows a practical, balanced, embodiment. The line 100 and line port 101 are again shown, as are the telephone port 103, high-pass filter 105 and ADSL port 106. Firstly it should be noted that a common-mode filtering choke T2 and associated resistors R1A, R1B between the telephone port 103 and the low-pass filter 102, and a second common mode filtering choke T6 with resistors R3A, R38 play no part in the filtering (note that the phasing of the windings of these differs from that of the remaining transformers within the low-pass filter 102).

The capacitors C4, C6 and C8 of Figure 5 are replaced by centre tapped series pairs C4A, C4B etc.; similarly C5 and C7 are replaced by pairs C5A, C5B, C7A, C7B. The functions of inductors L4, L5 are performed by transformers 14, T5 in a balanced arrangement.

As before there are two generalised immittance converters, the first, 300' receives balanced signals from C4A, C4B via d.c. blocking capacitors C2A, C2B. One signal is inverted by an amplifier IC1 with resistors R5A, R6, and the two signals summed via R5B, R7 into the input of a second amplifier IC2 whose h(s) 1 negative feed back path is provided by C3, R8 and R9. The transformer 304 is represented by transformer T3 with three windings phased as shown. The GIC 400' is identical to the GIC 300'.

The inductor L8 is represented by two transformers T8 and T9, the former with parallel resistors R4A, R4B outside the GIC's. This could be between the GIC's as a single transformer without resistance, but is placed outside to reduce the amount of high frequency ADSL signal received by the GIC itself. T8, T9, R4A and R4B represent an appropriately transformed version of the required inductance. The capacitor C11 is replaced by capacitor C11A, C11B in series (transformer C10 of the high-pass filter representing a short circuit at telephony frequencies). This capacitor is also outside the GIC's. Properly C11 should also undergo a transformation but this is not done for two reasons. C11 is also part of the high-pass filter and so cannot be transformed without side effects but the main problem is that the direct transformation of a capacitor requires an Frequency Dependent Negative Resistor (FDNR) which is unrealisable without further active elements. As this would be too exposed to the ADSL signal, and would cause linearity and noise problems, it is not done.

Resistors R2A, R2B (though not part of the prototype filter of Figure 5) are included to damp the parallel resonance of T4 and C5. This damping ensures stability of the active filter in the stopband when the filter is adversely terminated (including short and open-circuits).

Other sources of in-band loss are the resistances of the wound components and the failure to provide the correct transformation of the capacitor C11.

The high-pass filter 105 shares the capacitors C11A, C11B and also has a balun transformer T10 which also forms the first shunt inductor of the high-pass filter, which additionally includes further series capacitors C12, C13 and shunt inductors L10, L20.

Figure 7 shows a current GIC; here the current 11 at the right-hand port is sensed by a current transformer 501. This is converted into a current (h(s)-1) times as large by an amplifier 502 with a feedback resistor 503 of resistance R and a complex load impedance 504 of impedance R/(h(s)-1). The resulting current i_1(h(s)-1) is coupled into the left-hand port by coupling the power rail of the amplifier 502 to it in a d.c. blocking capacitor 505, so that the total current at the left-hand port is i_1.h(s). The power rail of the amplifier is fed with power via a

choke 506.

Claims

1. A telecommunications station comprising

   a line connection (101) connected to a transmission line (100) having a frequency dependent characteristic impedance;
   an impedance conversion arrangement (400) having two ports one of which is connected to the line connection; a conductive path between the ports so as to be substantially transparent to d.c. and to components exceeding a predetermined amplitude, and an amplifier connected to receive signals from the conductive path and to deliver to the conductive path a frequency-dependent function of the received signals; characterised by
   a high-pass filter (105) connected between the line connection (101) and means (107) for transmitting and/or receiving signals in an upper frequency band;
   a low-pass passive filter (200) connected between the other port of the impedance conversion arrangement (400) and telephony apparatus (104) for communication in a lower frequency band.

2. A telecommunications station according to claim 1, in which the impedance conversion arrangement (400) has a transfer function such that the characteristic impedance of the filter (200) is at least approximately matched to the characteristic impedance of the transmission line (100).

3. A telecommunications station according to Claim 1 or 2 including a second such impedance conversion arrangement (300) connected between the filter (200) and the telephony apparatus (104).

4. A telecommunications station according to claim 1, 2 or 3, in which the transmission line (100) is a twisted-pair line.

5. A telecommunications station according to any one of claims 1 to 4 in which the amplifier (301) is connected to receive the voltage at a first one of the ports, and to deliver the frequency-dependent function of this voltage to the primary winding of a transformer (303), and wherein a secondary winding of the transformer is connected into the conductive path between the ports such that the voltage at the second port is a predetermined function of that at the first, and the current at the two ports is the same.

6. A telecommunications station according to claim 5 for connection to a balanced line, in which first and second terminals of the first port are connected by first and second transformer secondary windings to first and second terminals of the second port.

7. A telecommunications station according to any one of claims 1 to 4 wherein a primary winding of a transformer (501) is connected into the conductive path between the ports to sense the current therein, and the amplifier (502) is connected to receive the output of the transformer (501) and to draw current from, or deliver current to, one of the ports as a frequency-dependent function of the sensed current, such that the current at the second port is a predetermined function of that at the first port and the voltage at the two ports is the same.

Patentansprüche

1. Telekommunikationsstation mit

   einem Leitungsanschluß (101), der an eine Übertragungsleitung (100) mit einer charakteristischen frequenzabhängigen Impedanz angeschlossen ist und

   einer Impedanzumwandlungsvorrichtung (400) mit zwei Anschlüssen, wobei einer an den Leitungsanschluß angeschlossen ist, mit einer leitenden Verbindung zwischen den Anschlüssen, die im wesentlichen für Gleichspannung und für Komponenten, die eine vorbestimmte Amplitude übersteigen, durchlässig ist, und mit einem angeschlossenen Verstärker, der Signale von der leitenden Verbindung empfängt und an die leitende Verbindung eine frequenzabhängige Funktion der empfangenen Signale ausgibt,

   gekennzeichnet durch

   ein Hochpaßfilter (105), das zwischen dem Leitungsanschluß (101) und Mitteln (107) zur Übertragung und/oder für den Empfang von Signalen in einem oberen Frequenzband angeordnet ist, und

   ein Tiefpaßfilter (200), das zwischen dem anderen Anschluß der Impedanzumwandlungsvorrichtung (400) und einer Telefonvorrichtung (104) zur Kommunikation in einem niedrigen Frequenzband angeordnet ist.

2. Telekommunikationsstation nach Anspruch 1, wobei die Impedanzumwandlungsvorrichtung (400) eine Übertragungsfunktion aufweist, bei der die charakteristische Impedanz des Filters (200) ungefähr

mit der charakteristischen Impedanz der Übertragungsleitung (100) übereinstimmt.

3. Telekommunikationsstation nach Anspruch 1 oder 2 mit einer zweiten Impedanzumwandlungsvorrichtung (300), die zwischen dem Filter (200) und der Telefonvorrichtung (104) angeschlossen ist.

4. Telekommunikationsstation nach Anspruch 1, 2 oder 3, wobei die Übertragungsleitung eine twisted-pair-Leitung ist.

5. Telekommunikationsstation nach einem der Ansprüche 1 bis 4, wobei der Verstärker (301) derart angeschlossen ist, daß die Spannung an einem ersten Eingang empfangen wird und daß die frequenzabhängige Funktion dieser Spannung an die Primärwicklung eines Transformators (303) geliefert wird, wobei eine Sekundärwicklung des Transformators so an den leitenden Abschnitt zwischen den Anschlüssen angeschlossen ist, daß die Spannung am zweiten Anschluß eine vorbestimmte Funktion des ersten Anschlusses ist, wobei der Strom bei beiden Anschlüssen gleich ist.

6. Telekommunikationsstation nach Anspruch 5 zum Anschluß an eine ausgeglichene Leitung, wobei die ersten und zweiten Anschlußpunkte des ersten Anschlusses durch erste und zweite Transformatorsekundärwicklung an erste und zweite Anschlußpunkte des zweiten Anschlusses angeschlossen sind.

7. Telekommunikationsstation nach einem der Ansprüche 1 bis 4, wobei eine Primärwicklung eines Transformators (501) an die leitende Verbindung zwischen den Anschlüssen angeschlossen ist, um den Strom darin zu erfassen, wobei der Verstärker (502) derart angeschlossen ist, daß die Ausgabe des Transformators (501) empfangen wird und in Abhängigkeit der frequenzabhängigen Funktion des abgetasteten Stroms Strom von einem der Anschlüsse abgezogen wird, oder ihm zugeführt wird, so daß der Strom beim zweiten Anschluß eine vorbestimmte Funktion des Stromes beim ersten Anschluß ist, wobei die Spannung bei beiden Anschlüssen gleich ist.

Revendications

1. Poste de télécommunications comprenant

   une connexion de ligne (101) connectée à une ligne de transmission (100) présentant une impédance caractéristique dépendante de la fréquence,
   un agencement de conversion d'impédance (400) comportant deux accès dont l'un est relié à la connexion de ligne, une voie conductrice entre les accès de façon à être pratiquement transparente pour les composantes en courant continu et pour les composantes dépassant une amplitude dépassant une amplitude prédéterminée, et un amplificateur relié de façon à recevoir des signaux provenant de la voie conductrice et pour délivrer à la voie conductrice une fonction dépendante de la fréquence des signaux reçus, caractérisé par
   un filtre passe-haut (105) relié entre la connexion de ligne (101) et un moyen (107) destiné à émettre et/ou recevoir des signaux dans une bande de fréquences supérieure,
   un filtre passif passe-bas (200) relié entre l'autre accès de l'agencement de conversion d'impédance (400) et l'appareil téléphonique (104) pour les communications dans une bande de fréquences inférieure.

2. Poste de télécommunications selon la revendication 1, dans lequel l'agencement de conversion d'impédance (400) présente une fonction de transfert telle que l'impédance caractéristique du filtre (200) est au moins approximativement adaptée à l'impédance caractéristique de la ligne de transmission (100).

3. Poste de télécommunications selon la revendication 1 ou 2 comprenant un second tel agencement de conversion d'impédance (300) relié entre le filtre (200) et l'appareil téléphonique (104).

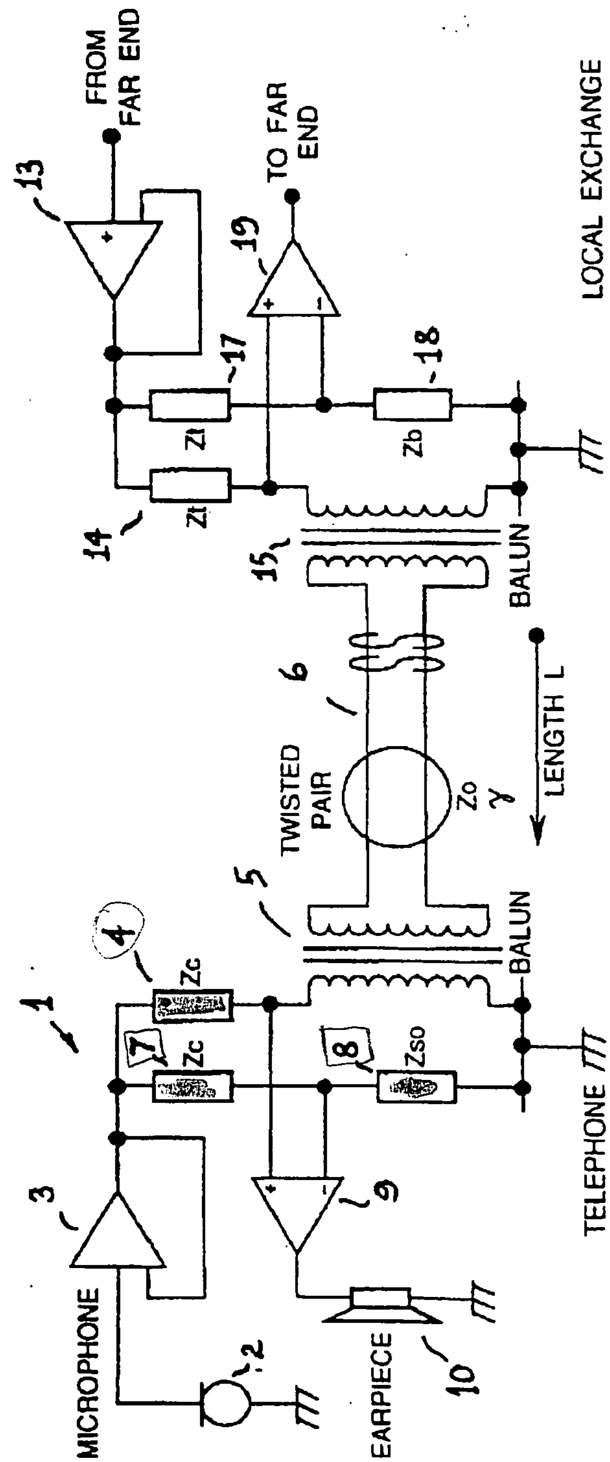
4. Poste de télécommunications selon la revendication 1, 2 ou 3, dans lequel la ligne de transmission (100) est une ligne à paire torsadée.

5. Poste de télécommunications selon l'une quelconque des revendications 1 à 4, dans lequel l'amplificateur (301) est relié de façon à recevoir la tension au niveau d'un premier des accès et à délivrer la fonction dépendante de la fréquence de cette tension à l'enroulement primaire d'un transformateur (303), et dans lequel un enroulement secondaire du transformateur est relié dans la voie conductrice entre les accès de façon à ce que la tension au niveau du second accès soit une fonction prédéterminée de celle au niveau du premier, et que le courant au niveau des deux accès soit le même.

6. Poste de télécommunications selon la revendication 5, destiné à une connexion à une ligne équilibrée, dans lequel des première et seconde bornes du premier accès sont reliées par des premier et second enroulements secondaires de transformateur à des première et seconde bornes du second accès.

7. Poste de télécommunications selon l'une quelconque des revendications 1 à 4, dans lequel un enroulement primaire d'un transformateur (501) est relié à la voie conductrice entre les accès afin de détecter le courant dans celle-ci, et l'amplificateur (502) est relié de façon à recevoir la sortie du transformateur (501) est d'extraire un courant depuis l'un des accès, ou de délivrer un courant à celui-ci, sous forme d'une fonction dépendante de la fréquence du courant détecté, de sorte que le courant au niveau du second accès est une fonction prédéterminée de celui au niveau du premier accès et que la tension au niveau des deux accès est la même.

Fig.1.


FROM FAR END
13
TO FAR END
19
17
18
Zt
Zt
Zb
14
15
BALUN
LOCAL EXCHANGE
6
TWISTED PAIR
Zo
γ
LENGTH L
5
BALUN
4
Zc
1
7
Zc
8
Zso
3
9
MICROPHONE
2
EARPIECE
10
TELEPHONE

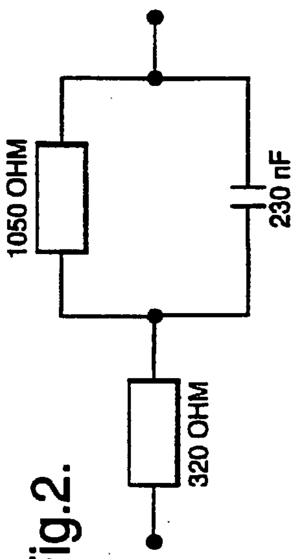

1050 OHM
230 nF
320 OHM

Fig.2.

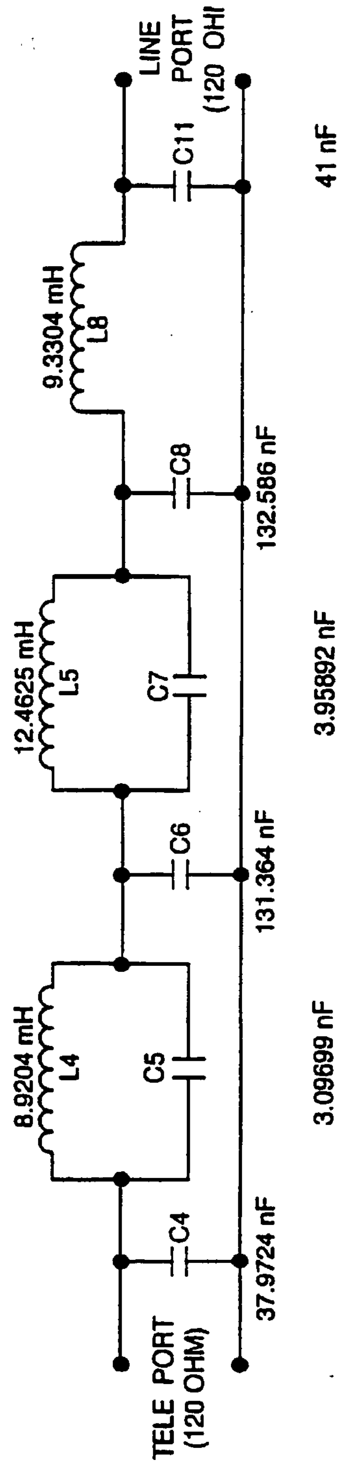

LINE
PORT
(120 OH
C11
41 nF
9.3304 mH
L8
C8
132.586 nF
12.4625 mH
L5
C7
3.95892 nF
C6
131.364 nF
8.9204 mH
L4
C5
3.09699 nF
C4
37.9724 nF
TELE PORT
(120 OHM)

Fig.5.

Fig.3.

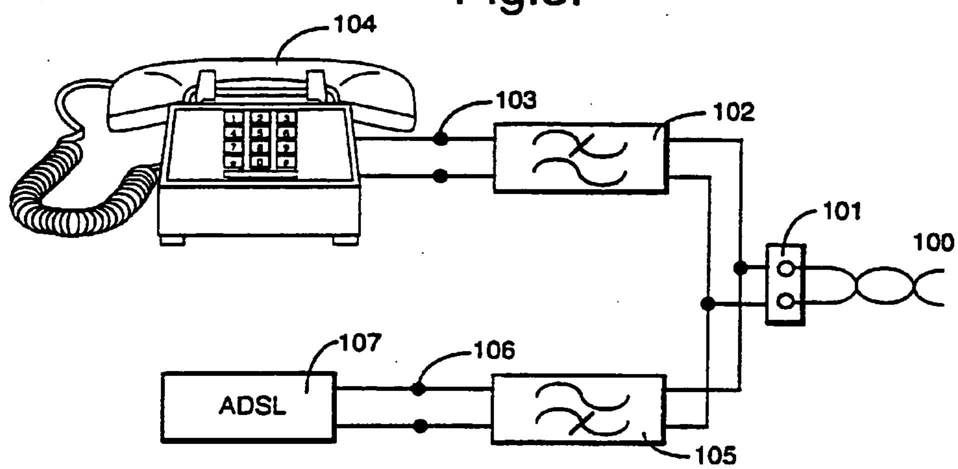

104
103
102
101
100
107
106
ADSL
105

Fig.7.

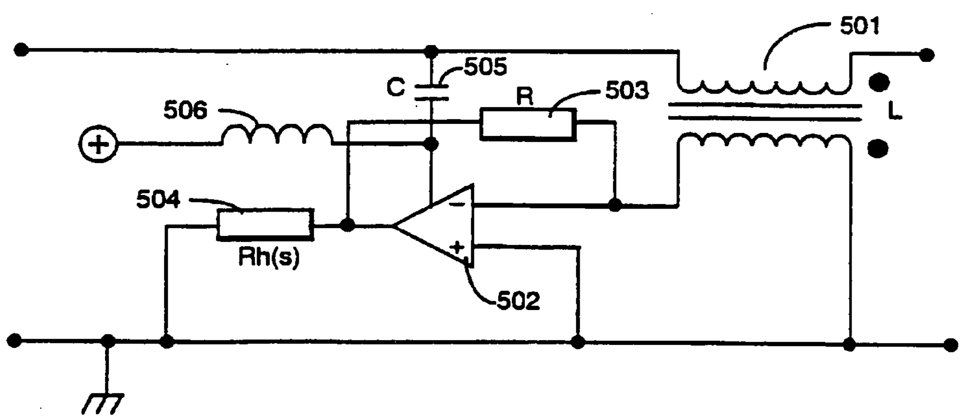
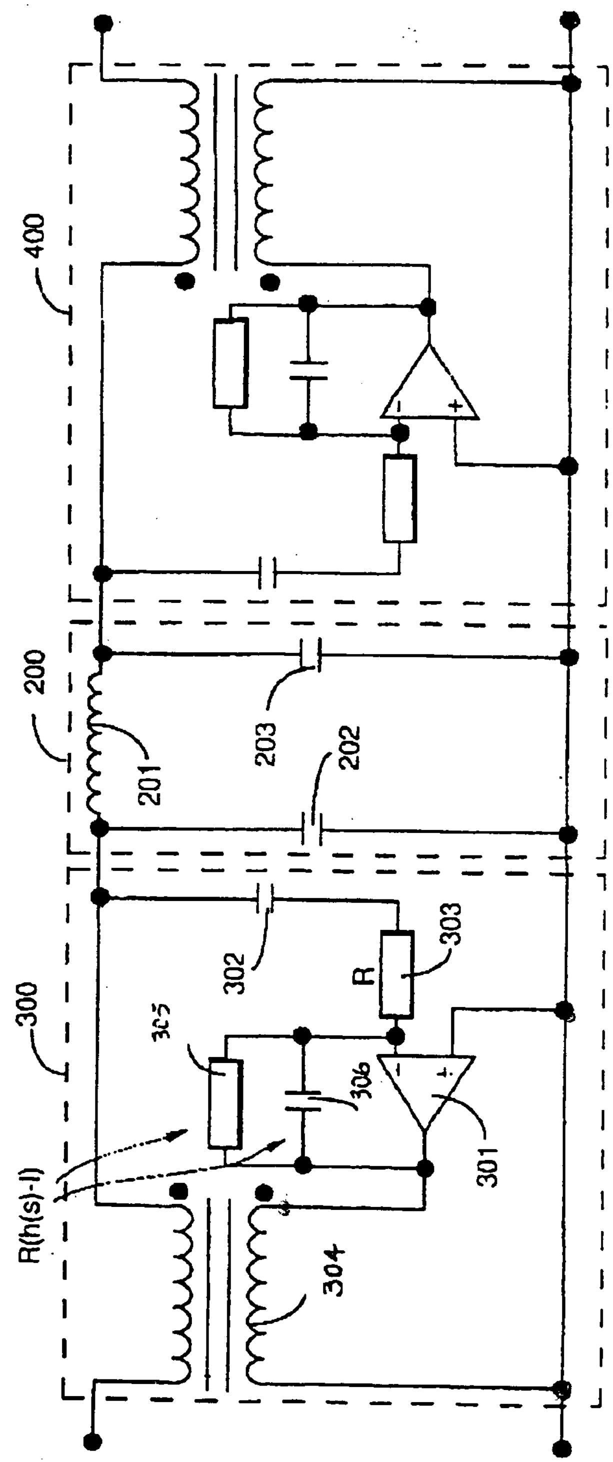
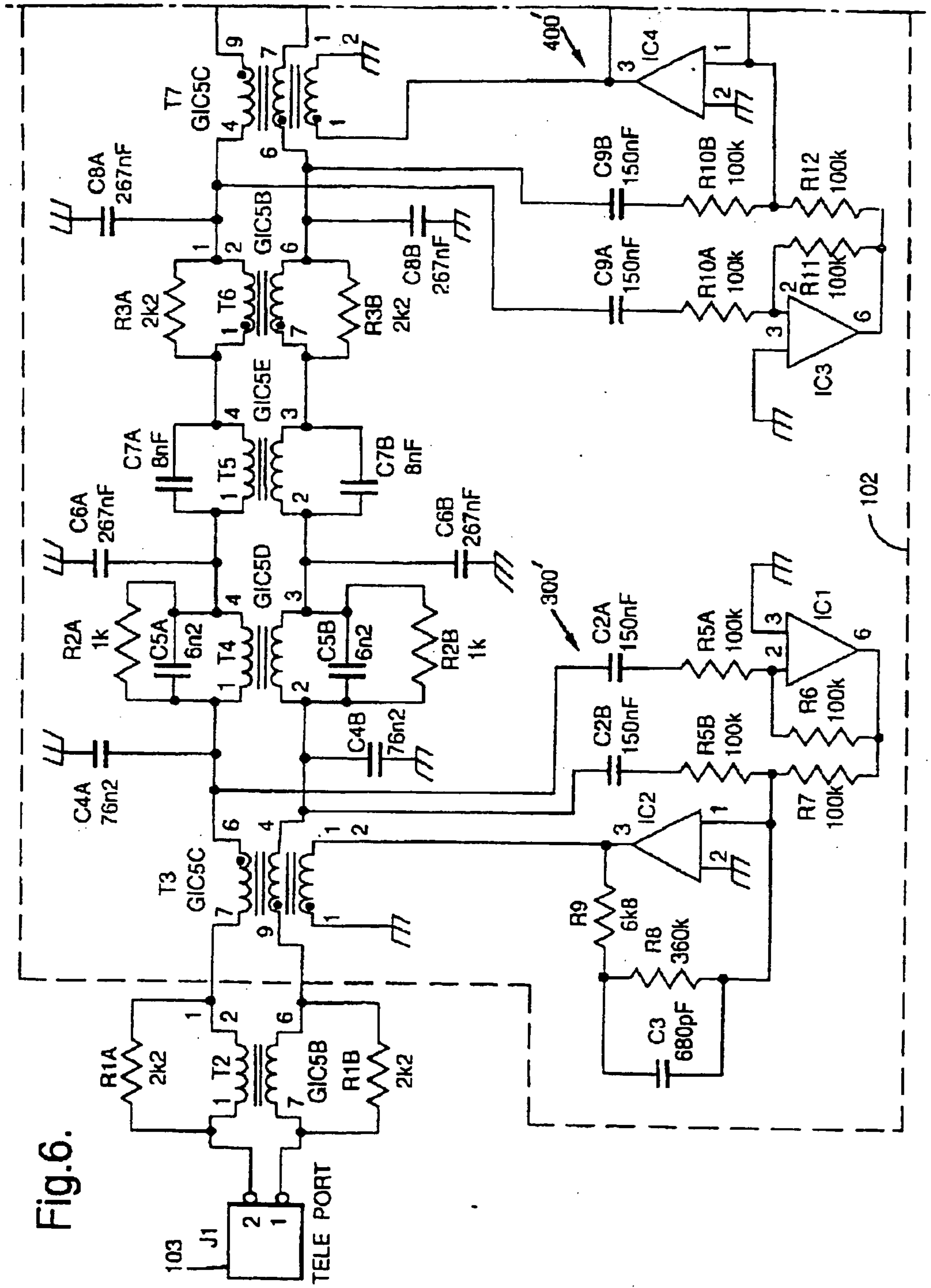

501
505
C
R
503
506
L
504
Rh(s)
502

Fig.4.




TELE PORT
J1
103
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R1B 2k2
T2 GIC5B
T3 GIC5C
C4A 76n2
C4B 76n2
R2A 1k
R2B 1k
C5A 6n2
C5B 6n2
T4 GIC5D
C6A 267nF
C6B 267nF
C7A 8nF
C7B 8nF
T5 GIC5E
R3A 2k2
R3B 2k2
T6 GIC5B
C8A 267nF
C8B 267nF
T7 GIC5C
400
IC4
C9A 150nF
C9B 150nF
R10A 100k
R10B 100k
R11 100k
R12 100k
IC3
102
300
C2A 150nF
C2B 150nF
R5A 100k
R5B 100k
R6 100k
R7 100k
IC1
IC2
R9 6k8
R8 360k
C3 680pF

Fig.6.

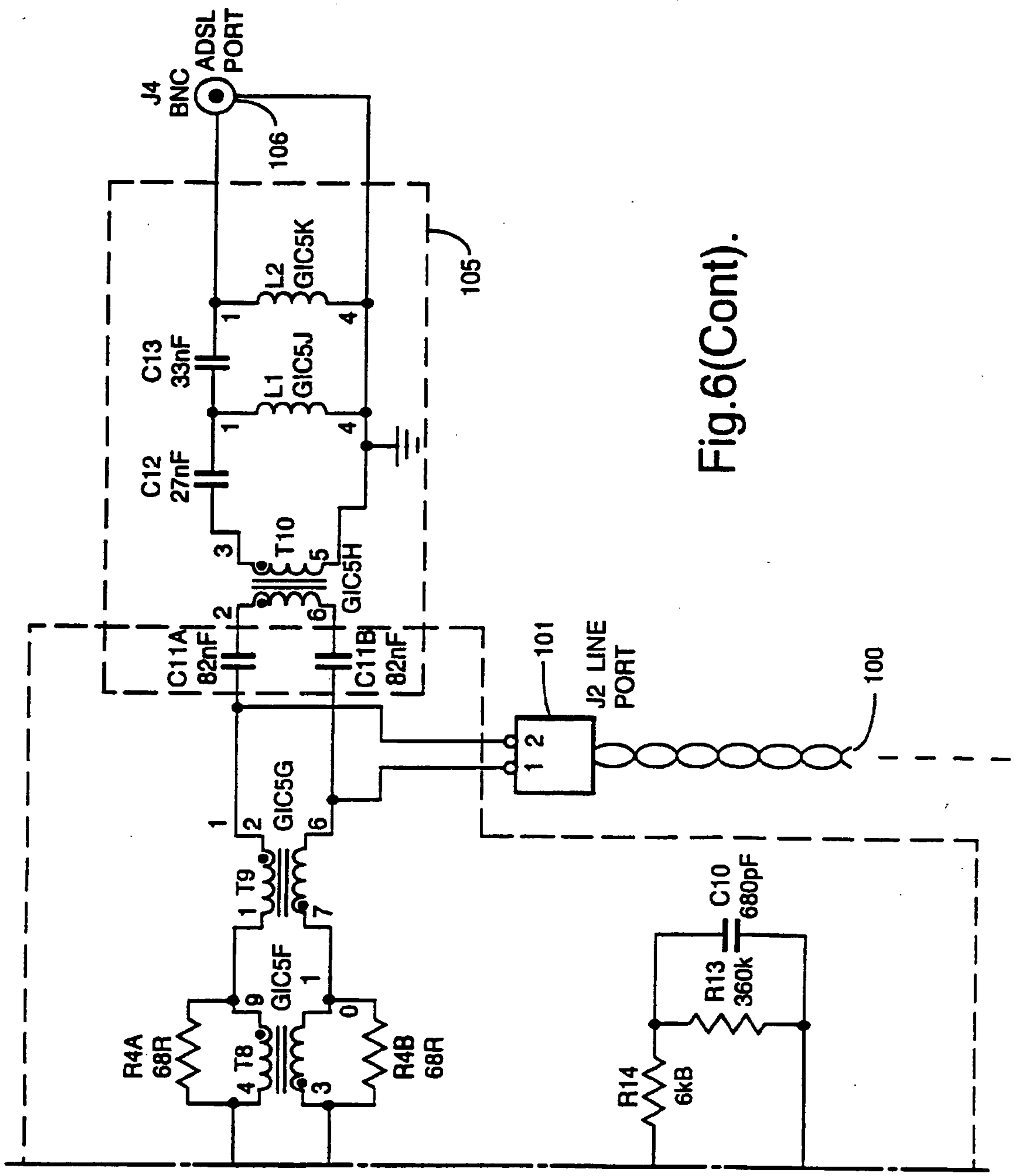
J4
BNC
ADSL
PORT
106
105
C13
33nF
C12
27nF
L2
GIC5K
L1
GIC5J
T10
GIC5H
C11A
82nF
C11B
82nF
101
J2 LINE
PORT
100
GIC5G
T9
GIC5F
T8
R4A
68R
R4B
68R
C10
680pF
R13
360k
R14
6kB

Fig.6(Cont).